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Emerging Large-Screen Display Technology

By

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13. ABSTRACT *(Maximum 200 words)*
Large-screen display technology is undergoing significant changes because of huge investments being expended to meet the potential high-definition television (HDTV) market. The expected result of this investment is display devices having improved quality and larger areas, which can be immediately used in military command and control operations. This report tracks recent display developments and their potential capabilities for command and control applications.

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PREFACE

The data and the products contained in this report are representative of the type of technology employed and the products offered in the marketplace or reported in the laboratory. Exclusions of technologies or products are to be viewed as an oversight and not a commentary on the lack of utility.

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INTRODUCTION

This report discusses large-screen display technologies in two major groupings: direct view and projection systems. Direct view systems produce full-sized images without projection optics. They produce images either by raster scanning, as with conventional televisions, or by controlling individual pixel elements, as in flat panels. Projection systems produce full-sized images through single or multiple sets of quality lenses, by scanning laser beams across the screen's surface, or by using a modulating medium (for example, film, viewgraph transparencies, liquid-crystal (LC), or oil) with a collimated, high-intensity light source. The latter class of projection systems is called light-valve systems, a leading candidate of future high-resolution, bright large-screen displays. Figure 1 shows the classification of large-screen displays, which guides the organization of this report.

One of the significant factors driving large-screen display development is the potentially large high-definition television (HDTV) market. New display devices are needed for this market. If one were to define an ideal HDTV system for home use, both day and night, it must provide bright 1125 to 1575 line images, on thin 40-inch diagonal screens at real-time rates without smear. The system must be affordable (today's premium television sets cost $1000) and display quality images soon after turn-on without requiring adjustment. This combination of performance is not possible now, but many companies, some with Government support, are actively developing HDTV display systems. As display companies meet the HDTV challenges, large-screen applications, such as military command and control, and electronic cinema, will benefit because their display requirements are similar. For example, military command and control operations display high-resolution workstation images on large areas [1,2]; future electronic cinemas require the same resolution or better but at higher brightness levels [3].

This report discusses the recent developments in full-color large-screen technologies, and a future report will address HDTV technologies requirements and development in greater detail. For all display technologies, this report discusses the technology status, the known limitations, and production status. The technology with the highest potential for success is the technology that meets most performance requirements, but more importantly has good manufacturing yields that will translate into a cost effective product in the marketplace.

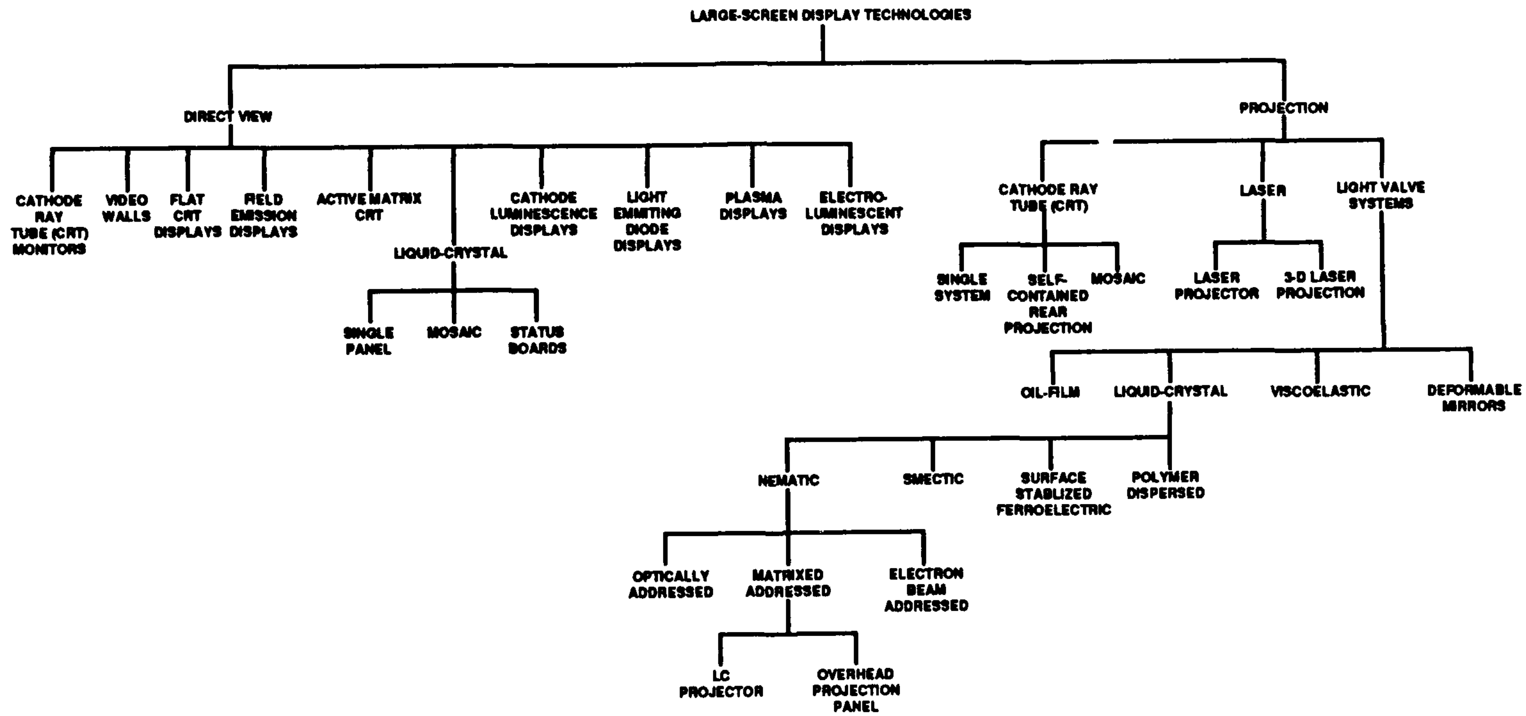

Figure 1. Large-Screen Display Technology Classification

SECTION 2

DIRECT VIEW SYSTEMS

2.1 CATHODE-RAY-TUBE MONITORS

Cathode-ray-tube (CRT) technology, the dominant display technology, provides unequalled display qualities in terms of luminance output, color performance, response time, and gray scale capabilities. Using CRT technology for large-area, high-resolution images is handicapped by increasing cost, size, and weight, and decreasing luminous efficiency (lumens per watt) [4].

For these reasons, most CRT systems are limited in size, which restrains their use for small groups. For example, 19- to 30-inch diagonal high-resolution (up to 2000 by 2000 pixels) CRT monitors are widely used in tactical command and control consoles, but only a few people can view the display at one time. For the consumer market, monitor manufacturers are offering HDTV quality monitors, but they are expensive. A 32-inch diagonal monitor costs $40,000; a 38-inch diagonal monitor costs $68,000. Larger CRT monitors are available, 43 inches for example, but they are limited to video graphics array (VGA) quality resolution (640 by 480 pixels).

2.2 VIDEO WALLS

System integrators have stacked multiple CRT monitors into one large composite image called a video wall. The total image is large and bright, but noticeable seams exist. The presentation is fine for video images, but falls short of satisfying command and control requirements.

2.3 FLAT CRT DISPLAYS

For years, manufacturers and universities have tried to use CRT technology in flat (thin) profiles because of the high luminous efficiency, the easily obtained gray scale and color qualities, and because CRT technology is well established and understood. While significant accomplishments were achieved in developing new flat CRT technologies, equally significant advances were made to lower the cost and enhance the performance of conventional CRT systems. Consequently, few flat CRT commercial successes resulted. For example, vacuum fluorescence displays (VFD), a $700 million worldwide market [5], are used only in small alphanumeric displays with limited color capabilities. Also, small flat CRT tubes have been produced for hand-held televisions, but they are now being replaced by LC technology.

In spite of these results, large-area flat CRT technology development continues in a couple of areas. The key challenge is to develop a cost efficient design with uniform performance that can be mass produced. Kanazawa Institute of Technology (KIT) is researching flat CRT displays for NEC that, they predict, can scale up to a 40-inch diagonal screen that is 4 inches thick [6]. The KIT design, shown in figure 2, uses small-diameter wires as line or multifilament cathodes instead of a single-point cathode. The emitted electron beam from the cathode is addressed by the vertical addressing electrode and then modulated in brightness by the modulation electrodes located behind the line cathode. For example, when the addressing electrode is -40 volts, no electron beam is emitted. When it is zero volts, the electron beam is emitted and modulated by applying 0 volts (maximum brightness) to -40 volts (electron beam is cut off) to the modulation electrode. The beam is then focused and deflected by the horizontal electrodes before landing on the anode electrode, which contains the phosphor material. KIT researchers have already demonstrated a monochrome, 110 by 26 pixel image on a 20 by 20 millimeter area; their next goal is building a full-color, 34-inch display having 700 by 500 pixel resolution. Matsushita also reported an experimental flat-panel CRT design [7], similar in concept to the KIT design.

2.4 FIELD-EMISSION DISPLAYS

Another flat panel CRT technology is field-emission display (FED) or vacuum microelectronics technology. Many industry experts expressed optimism in this technology at the 1991 International Vacuum Microelectronics Conference in Tokyo, Japan, but they feel that insufficient funding, not technical problems, is preventing the technology from being commercialized.

For example, Coloray Display Corporation is engineering a FED device using research conducted at SRI International in the late 1960s [8]. This display, shown in figure 3, uses an array of submicron-sized field emission tips placed extremely close to the electrodes to accelerate the electrons to a dedicated phosphor area. This technology has several advantages—it requires low voltages (30 to 100 volts), the display assembly is thin, and 10 to 100 one-micron-diameter emitters can be packed into each pixel location to provide redundancy for high reliability and good luminance uniformity. The technical challenges are to extend the lifetime of the cathode tips, achieve low manufacturing costs, and obtain efficiency phosphors [9].

The Defense Advanced Research Projects Agency (DARPA) has supported a 1990 development of a small area prototype, and Coloray has started to engineer its first product for laptop computers. However, in July 1991, the "Electronic Engineering Times" reported

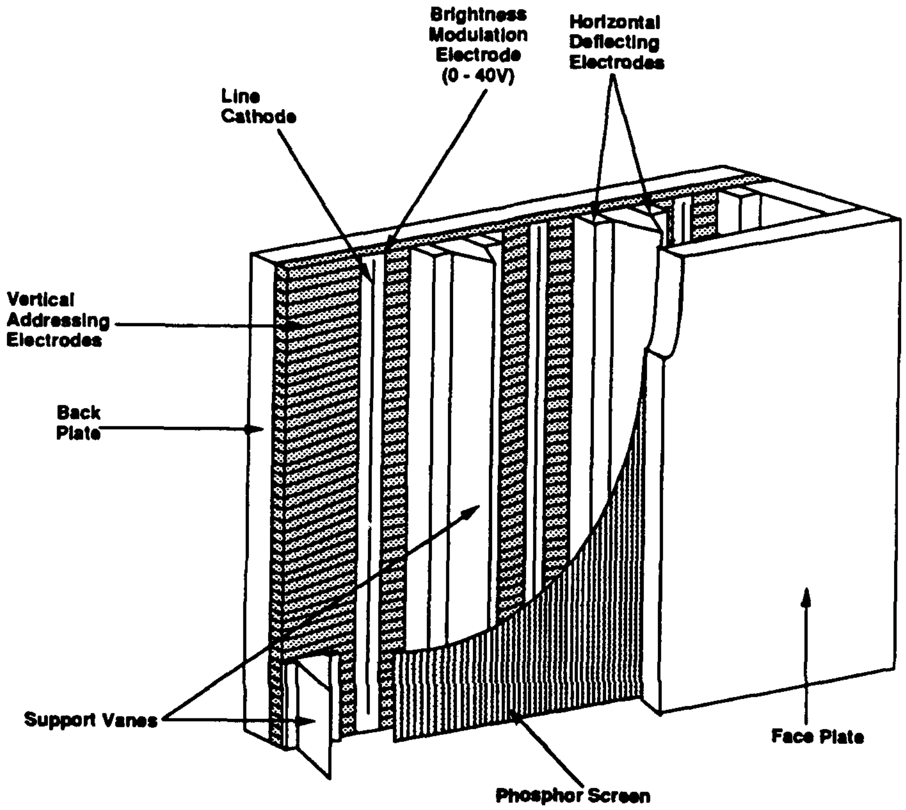

Figure 2. Kanazawa Institute of Technology Flat Large-Area CRT

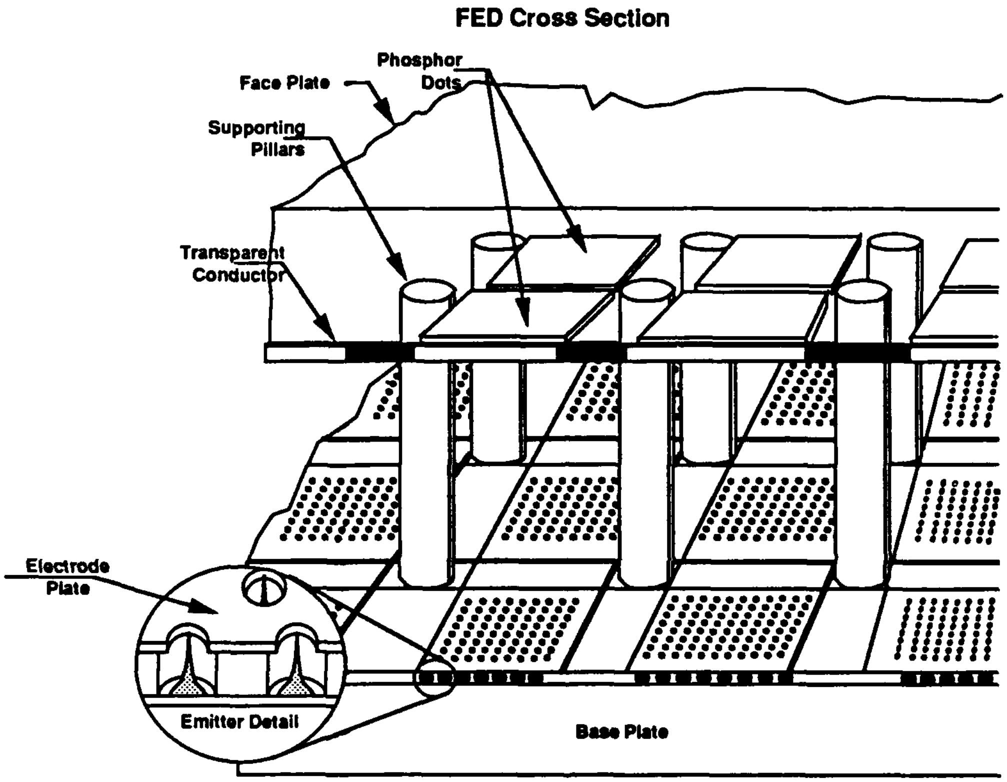

Figure 3. Coloray Field-Emission Display

that Coloray shelved their FED program because they could not get required financial support. The consortium, Microelectronics and Computer Technology Corporation (MCC), is also developing the FED technology based on the composite emitter developed by A. Christenson at Texas A&M University. Late in 1991, MCC initiated an effort to pool together the resources of several companies working with FED technology.

2.5 ACTIVE-MATRIX CRT

A third approach, abandoned in the 1970s by Arizona State [10], merits serious consideration, considering recent advances in photolithography technology. This approach also uses multifilament cathodes with a thin-film layer of colored phosphor dots collocated with thin-film-transistor (TFT) devices. When a TFT device is activated, the electric field is established, propelling the electrons to the phosphor area. To our knowledge, no one is developing this concept.

2.6 LIQUID-CRYSTAL PANELS

2.6.1 Single Active-Matrix Liquid-Crystal Displays

Because of the size of development investment, active-matrix liquid-crystal display (AMLCD) technology may have the greatest potential for HDTV displays. AMLCD panels use amorphous silicon or polycrystalline silicon TFT to switch pixel-sized areas of twisted nematic LC material. Twisted nematic LC material (figure 4) is characterized by well-ordered molecules that have freedoms of movement as if they were in a liquid state. The molecular orientation is easily changed by electric fields to alter the direction of polarized light that can be detected by polarizing filters.

The Japanese Ministry of International Trade and Industry (MITI) has organized a Government-supported consortium to develop a one-meter square AMLCD panel only 1-inch thick—a television screen that hangs on the wall. In spite of the investments, the MITI goal, at best, must be considered long term (10 years), and most companies are now concentrating on small AMLCD panel sizes. At the recent Japanese Flat Panel Display Technology Workshop, Lawrence Tannas [11] stated that the Japanese are focusing their development on 3 to 16-inch diagonal color AMLCD panels, and predicts the television on the wall is not possible before the year 2000.

Sharp, one of the industry leaders, has just introduced an 8.6-inch-diagonal AMLCD panel with a 960 by 460 pixel resolution that costs $4000, and plans to market a $360, 10-inch panel in 1995. Cited as a major technical breakthrough, Toshiba showed their 1,152 by 900 pixel resolution AMLCD on a 13.8-inch screen at the 1991 Comdex Show in November.

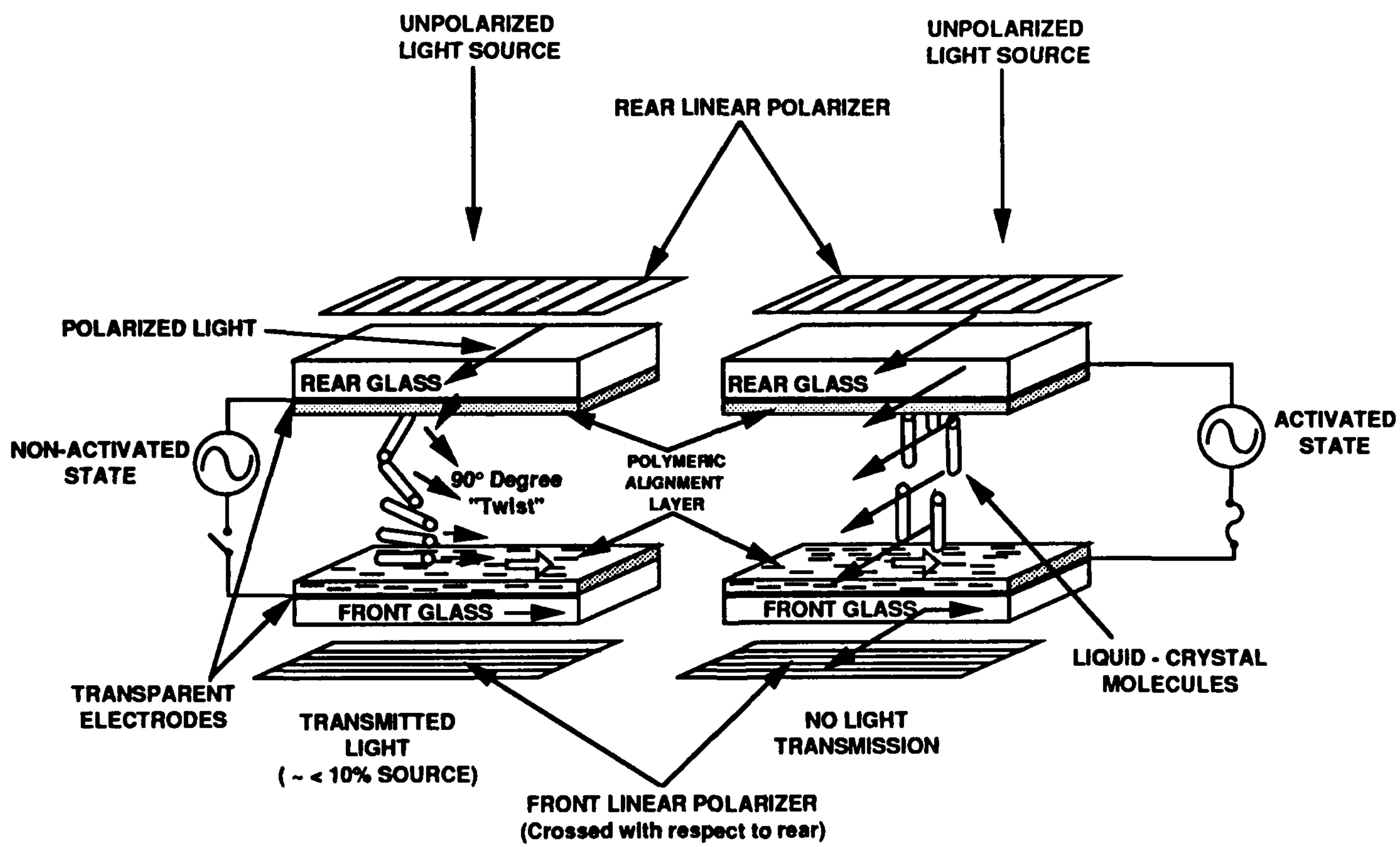

Figure 4. Twisted Nematic Liquid-Crystal Display

Until the display companies improve their manufacturing yields, reported to be no better than 30 percent on 8-inch panels and 10 percent on 14-inch panels, reasonably priced, large AMLCD panels will not be available soon. Except for console displays and portable workstations or low-resolution mosaic panels, command and control centers cannot take advantage of this technology.

Because commercial success depends on obtaining affordable AMLCD displays, improved manufacturing yields is a top industry priority. The solutions are varied and include improved material and manufacturing processes, noncontact inspection and panel repair, redundant circuit designs, and alternative devices to replace the TFT devices. The TFT alternatives are magnetic thin-film switches, diodes, metal-insulator-metal (MIM) devices, and other two-terminal devices. Tektronix is developing a plasma switching design that uses the ionization properties of neon gas [12]. When the gas is ionized, the switch is on; and when deionized, it is off. Gray scale is possible because the mobility and number of ionized carriers determine the switch's conductivity. Tektronix has demonstrated a 90,000 pixel, 5 by 5-inch panel operating with gray scale capabilities at video rates.

2.6.2 Mosaic Liquid-Crystal Displays

Some manufacturers use a multiple backlit liquid-crystal display (LCD) modules to construct large area mosaic displays. The pixel density is low (1.6 to 4 pixels per inch); therefore, only low-resolution systems have been used for command and control status boards. In one application, a 7- by 5.3-foot Panasonic panel that is only 16 inches deep provides 320 by 104 pixels. It is backlit by fluorescent lamps to provide over 1000 lumens and consumes over 4 kW of power.

In January 1991, Matra Defense, a French company, announced a high-resolution, modular LC display system, called Grand X, developed for the French Navy. Matra claims they can build display areas up to 36 square meters that is 1 meter thick. Smaller panels are thinner. For example, a 1-square-meter display area is only 35 centimeters thick. In the United States, Magnascreen Corporation is using the same approach to develop a seamless LCD panel for DARPA. Their design goal is a 1-meter diagonal, 1000-line display.

2.6.3 Status Boards

Noteworthy, because of the size of commitment, is AEG's construction of Europe's largest LCD manufacturing facility to produce large-area information board displays using twisted nematic LCDs with chip-on-glass technology purchased from Hitachi. These monochrome displays are ideal to replace the electromechanical systems used in transportation terminals and in status/message boards [13].

2.7 CATHODE LUMINESCENCE DISPLAYS

Two low-resolution, large-area displays, Jumbotron by Sony [14] and Diamond Vision Screen by Mitsubishi, use small area (0.1 by 0.3 inches) CRT devices to provide bright images for outdoor use. The pixel density is low (less than 2 pixels/inch), making these displays appropriate only for outdoors or large auditoriums. ISE Electronics Corporation and Mitsubishi recently presented an improved electrode design that doubles the pixel density to 3.4 pixels/inch [15].

2.8 LIGHT EMITTING DIODE DISPLAYS

Large-area, low-resolution display boards have been constructed with bi-color (red and green) light emitting diodes (LEDs). With a limited gray scale capability, yellow and orange colors can also be displayed. Current bi-color LED pixel densities are approximately 4 to 6 pixels/inch, which restricts the applications to status, advertising, and message boards. When researchers develop efficient blue-colored LEDs and at least eight levels of gray, full-color display capabilities can be achieved.

Teledyne showed their blue LED at the 1991 Society of Information Display (SID) conference, and Sanyo has started to ship sample quantities of a new blue LED design made from silicon carbide material. Once production costs are reduced, quantity shipments will start late 1992 [16].

Stanley Electric's full-color panel uses red and green LEDs, but substitutes blue fluorescent light coupled through fiber optics and ferroelectric LC switches for the blue pixel elements. Stanley Electric is also developing a blue LED. Ledtronics markets a RGB LED, but its use is limited by high cost and power consumption. Industry experts do not expect full-color LED panels for five years.

2.9 PLASMA DISPLAYS

Plasma technology is a leading HDTV candidate. Although plasma panels are typically monochrome, full color is achieved by using the ultraviolet light generated by the special gas discharge to excite red-green-blue (RGB) phosphor patterns (figure 5). Manufacturers claim that once the full-color capabilities are developed, they can easily scale the design to larger areas. Lawrence Tannas stated at the November 1991 Japanese Flat Panel Display Technology Workshop that Japanese companies are changing their HDTV emphasis from developing large AMLCD and electroluminescent panels to large color plasma panels. In fact, they are creating a Japan Key Technology Center (JKTC) consortium for HDTV plasma panels.

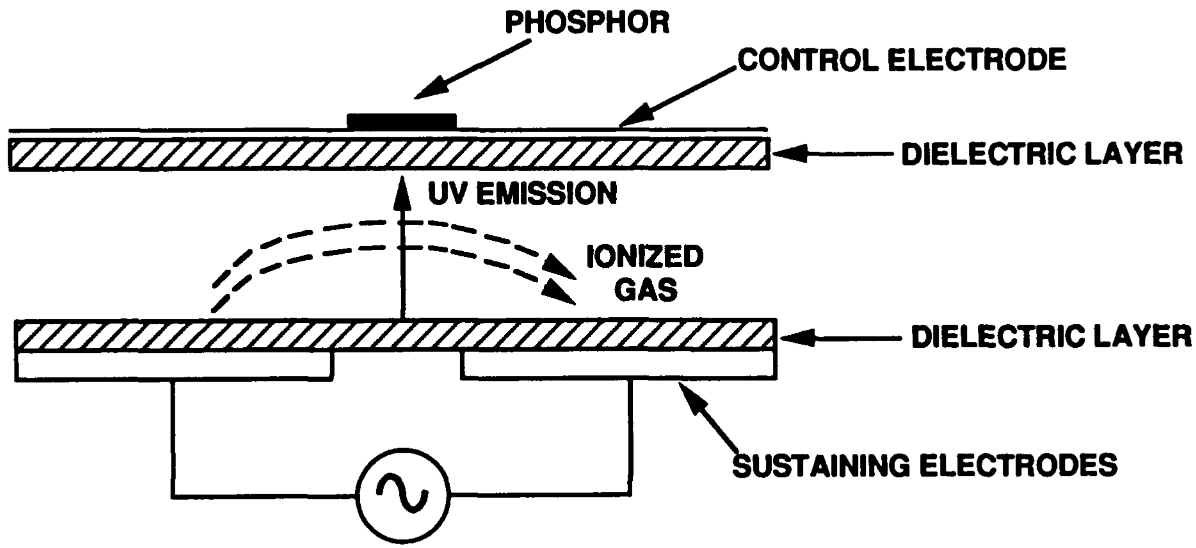

Figure 5. Color AC Plasma Display

Japan Broadcasting Company (NHK) has already demonstrated a 400-line, 33-inch, full-color DC plasma panel, specifically targeted for home use. A 40-inch DC plasma panel is now being developed with the goal of producing a 55-inch panel [17]. The French company Thomson Tubes Electroniques, in 1990, presented a 17-inch, 384 by 384 pixel, 8-color AC plasma panel, and plans a 23-inch, 1280 by 1280 pixel panel in 1991 [18]. In the United States, Photonics demonstrated, as a first phase of a DARPA funded project, a 17-inch AC plasma panel with 340 by 256 pixel, full-color resolution. In the second phase, Photonics plans to build a 50-inch-diagonal panel, with 1024 by 768 pixel, full-color resolution and predicts a $1000, 40-inch panel by 1993 [19-21]. Improved blue phosphors and lower manufacturing costs are key to the successful use of full-color plasma displays.

2.10 THIN-FILM ELECTROLUMINESCENT DISPLAYS

Color thin-film electroluminescent (TFEL) panels (figure 6) use a layer of thin-film, RGB phosphor patterns arranged similarly to shadow mask CRTs. The phosphor layer is sandwiched between two thin dielectric layers and two layers of electrodes for the row and column matrix drives. When a sufficiently high potential difference is applied, the phosphor area intersected by the electrodes is illuminated.

Full-color TFEL panel development has lagged full-color plasma achievements. Recently, Planar introduced a 9-inch TFEL with only three colors (red, green, and yellow). In 1988, Planar announced a 6-inch, 320 by 240 pixel, full-color panel with commercial introduction planned in 1990. These plans were later delayed, but with recent funding of $2.5 million from DARPA and the U. S. Army, they now plan a full-color 640 by 480 pixel, 10.6-inch TFEL panel in 1993.

Although manufacturers claim TFEL technology is competitive to other flat panel technologies, full-color panels require more efficient blue phosphors [22]. As with other flat-panel technologies, until the display companies reduce the manufacturing costs substantially, mass commercialization will not happen.

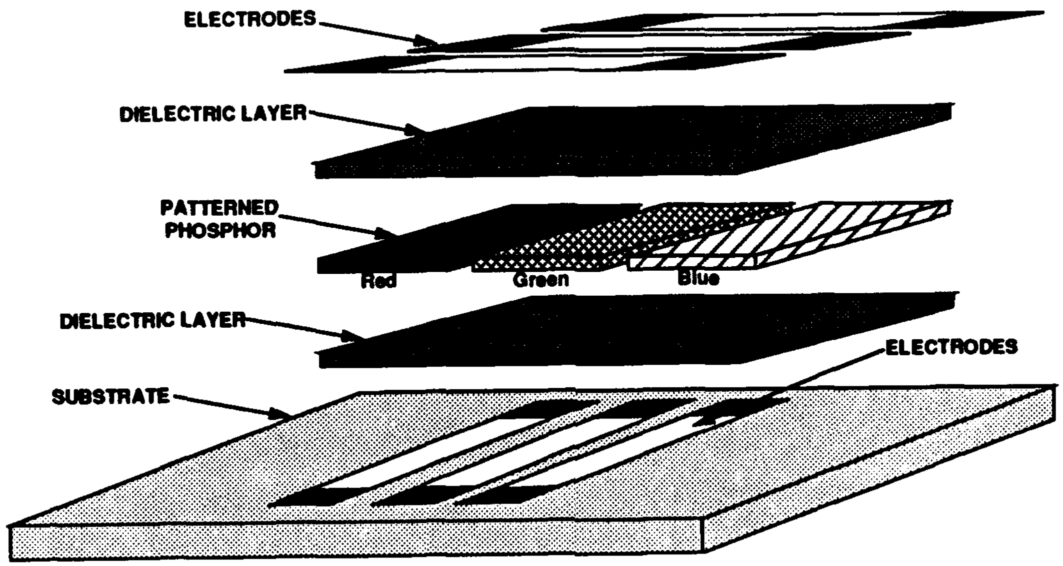

Figure 6. Color Thin-Film Electroluminescent Display

SECTION 3

PROJECTION SYSTEMS

3.1 CRT PROJECTION SYSTEMS

3.1.1 Single CRT Projection Systems

CRT projection systems, shown in figure 7, combine three monochrome CRT assemblies with projection lenses to produce quality images. CRT systems are widely used to brief strategic and tactical data developed on high performance workstations.

Using CRT technology in command centers requires additional attention to assure satisfactory performance. Large military command centers with display areas greater than 100 square feet generally do not use projection CRT systems because of inherent resolution-luminance performance limitations. For example, increasing the brightness increases the CRT's electron beam width and reduces the resolution to unacceptable levels. Yet, because of low cost (for example, $20K), command centers are using CRT systems when the display area is 50 square feet or less. Their use requires careful attention to the facility design to ensure the ambient light levels are low at the screen surface, and the viewing area is well designed. For example, the decision makers may have to be closer to the screen to view mission-critical information, or the characters and symbols may have to be larger, displayed in colors of sufficient contrast, and thicker than single pixel widths. Without this careful design attention, CRT projection performance will be unsatisfactory, which may constrain the operation.

New CRT projection designs are becoming more stable with digital designs and user-friendly features. They include infrared remote control devices, automatic signal synchronization from 15 to 80 kHz, storage of different set-up files to accept multiple video sources, on-line system setup and diagnostic aids, and, most recently, automatic convergence control [23].

The full HDTV performance goals may still be elusive for CRT projection systems; 1000-line resolution is achievable only at reduced luminance levels. Thus, satisfactory use is possible only in dimmed rooms. Manufacturers are developing larger CRT tubes and improving phosphor efficiencies, but the gap between actual performance and the full HDTV requirements may be too large to bridge without wholesale technology changes.

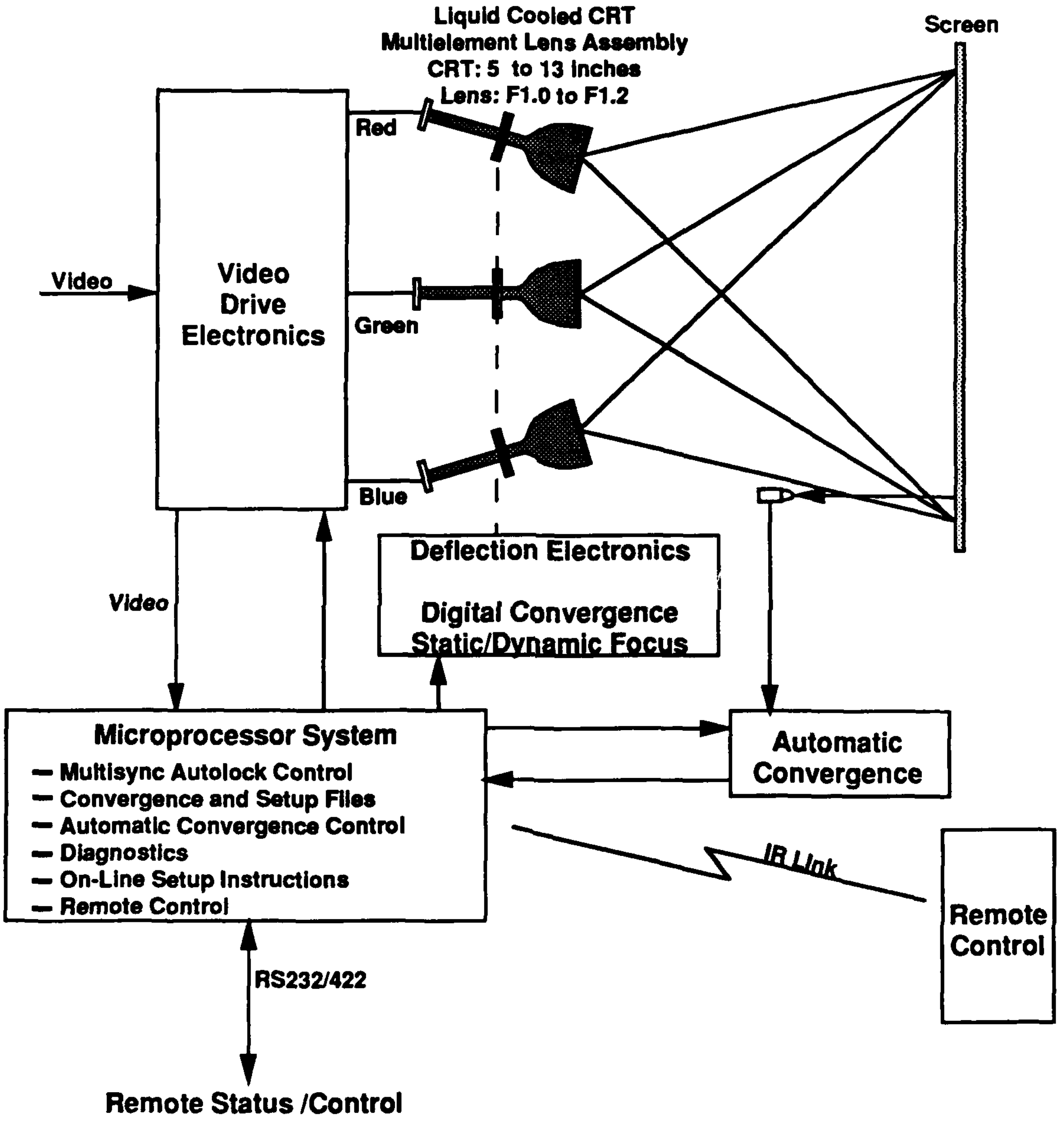

Figure 7. CRT Projection Systems

3.1.2 Self-Contained Rear-Projection CRT Systems

Several manufacturers have packaged the three CRT assemblies inside a cabinet (figure 8) with folded optics and a 50- to 100-inch-diagonal, high-gain lenticular rear-projection screen, some with black stripes for bright images with good contrast ratios. Because of the narrow viewing angles of the high-gain screens, the presentation is acceptable only for small-group viewing, such as the commander's battle control room (typically referred to as the battlecab).

Some manufacturers have extended this concept with multiple numbers of CRT assemblies—12 for example—to output bright images on larger high-gain screens, 250-inch diagonal. This design has not yet been proven and may not be practical. Aligning multiple images on top of each other for increased brightness is difficult and will reduce the total resolution performance. Additionally, the high-gain screen will have severe off-axis luminance falloff that is not acceptable for most command and control facilities.

3.1.3 Mosaic CRT Projection Systems

Multiple sets of RGB CRT projection systems have been effectively used in high-performance simulation systems. Real-time image processing hardware subdivides the total image into synchronized inputs to the individual projection systems. Because the human eye is sensitive to abrupt discontinuities, system designers must match luminance, chromaticity, and geometric parameters at the image boundaries. Most CRT projection systems have special designs for uniform performance, but at the cost of lower luminance outputs.

3.2 LASER

3.2.1 Laser Projection

Laser projection systems have the potential to display sharp, high contrast images with saturated colors. Existing system designs (figure 9) raster scan the output of argon-ion and dye lasers [24]. Some systems use rotating multiple faceted polygon mirrors (for example, 36-faceted polygon mirror rotating at 60,000 rpm) for the "line scanner" and a galvanometrically controlled flat mirror for the "frame scanner." Other systems use acoustic-optical (AO) or electro-optical technology for the "line scanner" and multifaceted drum or acoustic for the "frame scanners." These scanning techniques can display images with 350 to 1100 line resolution, refreshed 30 to 70 times a second.

Laser systems have several problems, including high power consumption, stringent water cooling requirements, low efficiency, and performance that demands perfect mechanical operation and alignment. Laser projection systems also exhibit speckle, caused

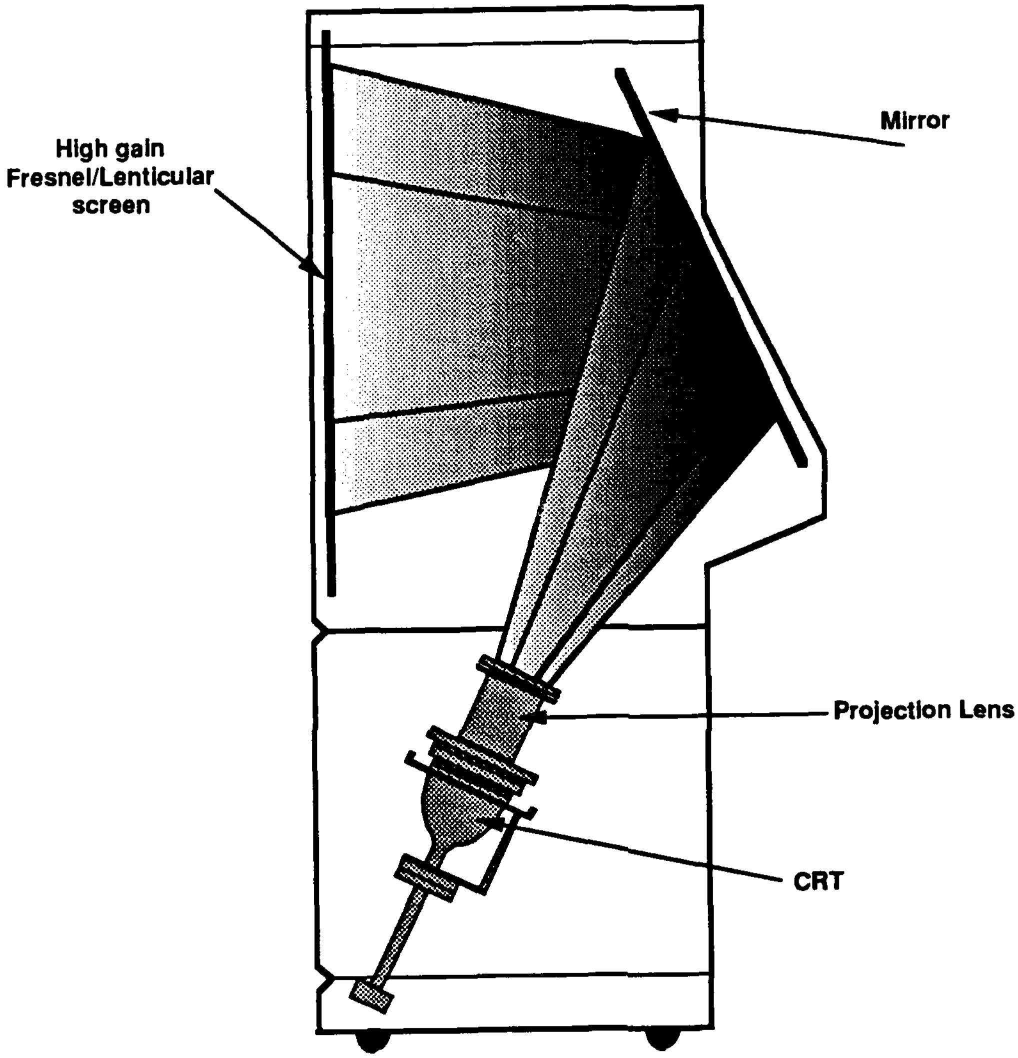

Figure 8. Self-Contained Rear-Projection CRT System

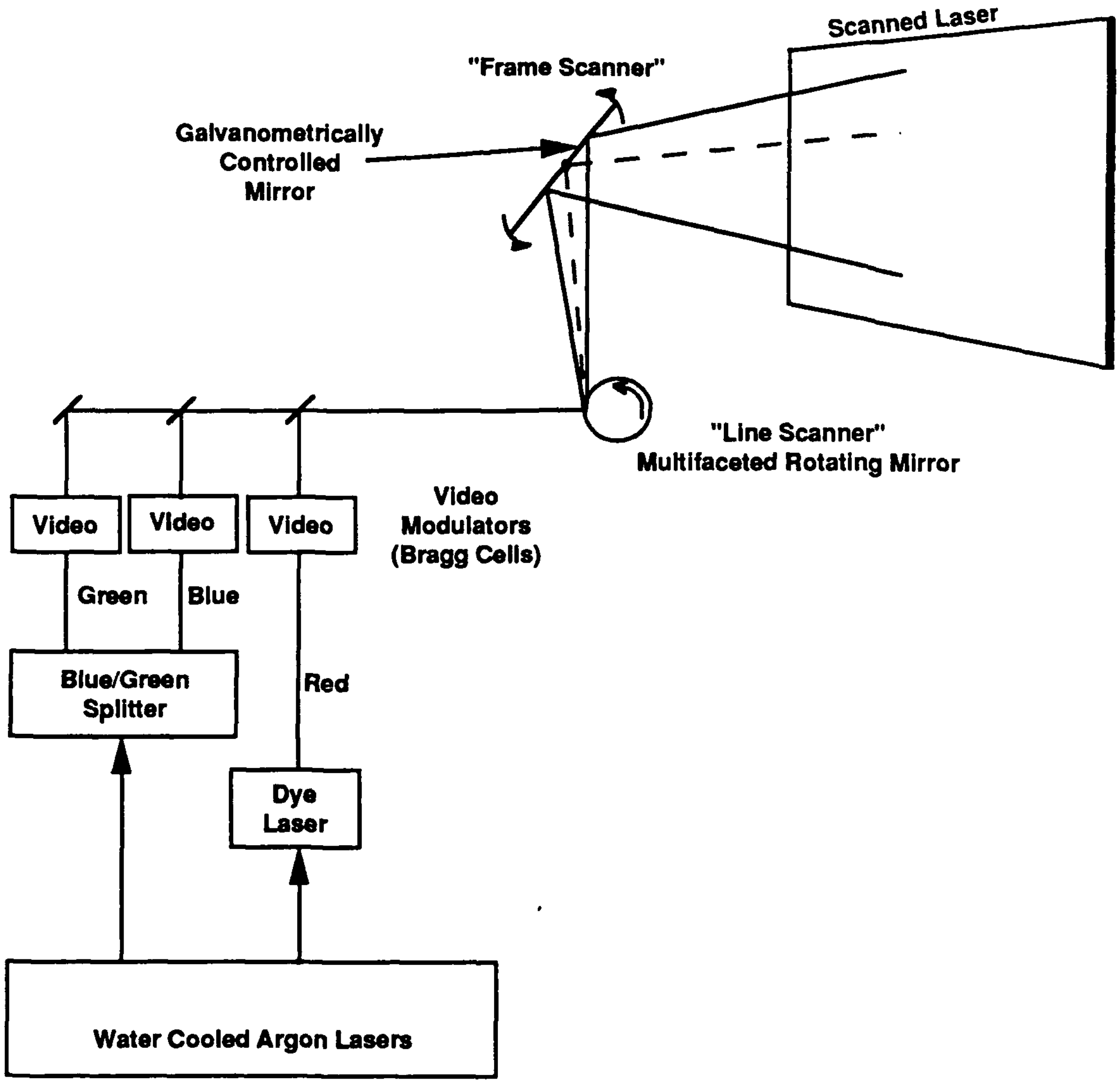

Figure 9. Laser Projection System

by interference patterns due to coherent light. Observers have claimed speckle increases brightness perceptions but degrades image qualities. Laser Creation (UK) recently presented their HDTV system at the 1991 SPIE Symposium on Electronic Imaging Science and Technology and claimed to project a speckle-free HDTV image on a wall of flowing water. Nitcor, a California company, is also developing laser technology for DARPA.

3.2.2 3-D Laser Projection Systems

Texas Instruments has developed a 3-D visualization display system using laser technology [25]. Their "Omniview" system, shown in figure 10, uses AO devices to scan a laser beam in an XY coordinate plane on a rotating translucent disk. As the beam is scanned, AO "Bragg cells" modulate the beam's intensity in synchronism with the rotating disk to write light voxels in the Z dimension. Texas Instruments has built a single color system using a 150 mW argon laser to produce 10-footlambert green images on a 21-inch disk with 500 by 500 pixel resolution. They are now building a larger (3-foot-diameter), multicolor system for delivery in late 1991. Shibaura Institute of Technology is also researching a 3-D display using argon lasers and a rotating curved screen [26].

3.3 LIGHT-VALVE SYSTEMS

Light-valve systems may have the greatest near-term potential for bright, high-resolution, large-area systems. Light-valves use oil films or LC material as a modulating medium to control the light projected from a high intensity source. All companies that market light-valve systems have or are improving their products for HDTV quality standards.

3.3.1 Oil-Film Light-Valve Systems

General Electric (figure 11) and Gretag (figure 12) both have produced oil-film, light-valve systems for several years, and both have shown bright HDTV quality designs. They are large systems, used primarily for large audiences in auditoriums or outdoors. Oil-film light-valves use an oil film for the modulating medium and Schlieren optics to filter the defracted light patterns. When the oil is disturbed by an electron beam, the light is diffracted and allowed to pass through a series of grating bars and the output optics.

Oil-film systems are limited to horizontal scan frequencies below 35 kHz, which may be a problem for new command and control facilities that are using high-resolution work-stations operating above 35 kHz. Manufacturers are offering convertors to reduce the workstation scan frequency to the oil-film system's operating range at the cost of decreasing the refresh rate or resolution.

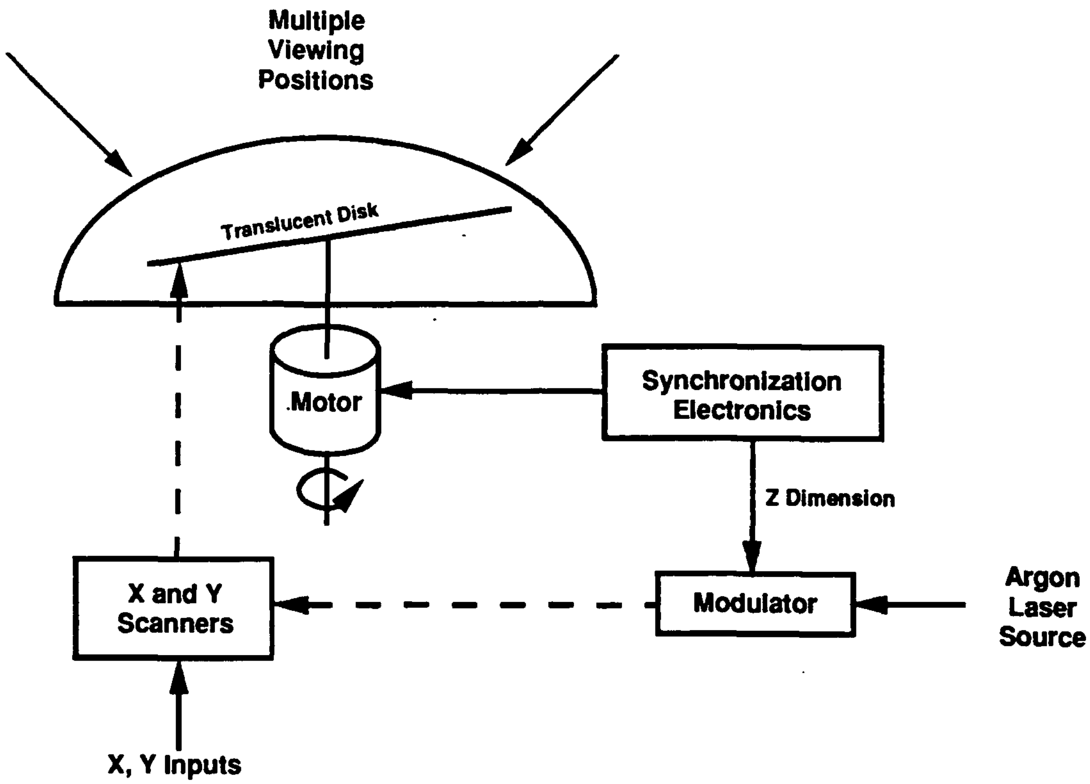

Figure 10. Texas Instruments 3-D Display System

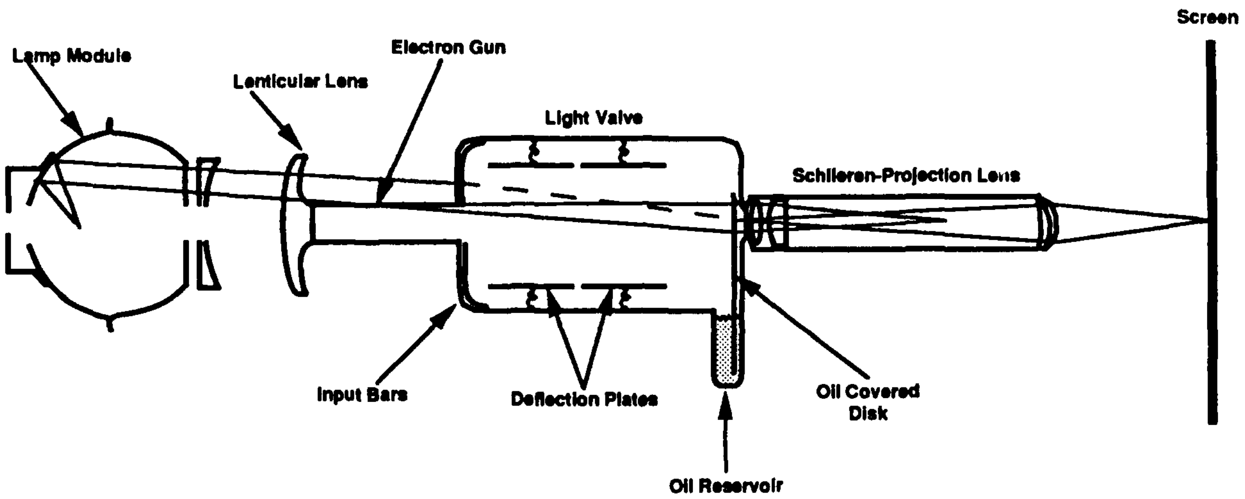

Figure 11. General Electric Oil-Film Light-Valve System

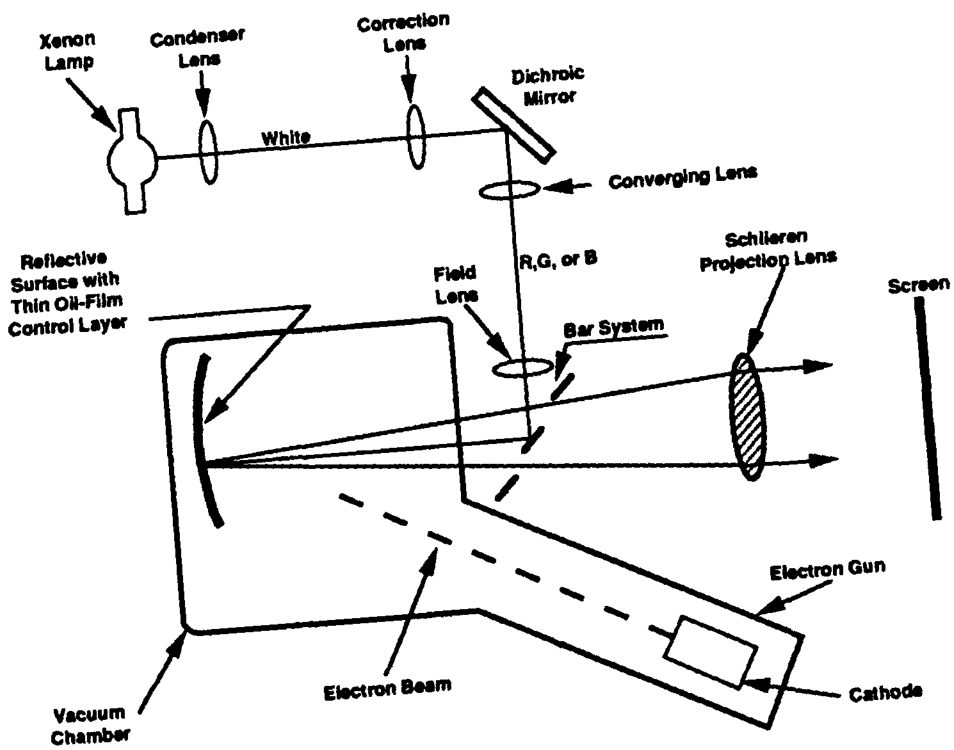

Figure 12. Gretag (Eidophor) Oil-Film Light-Valve System

Oil-film light-valves also require a specific oil temperature for each scan frequency. For applications that use multiple frequencies, the operator must adjust the oil temperature for each frequency, and it takes 20 to 30 minutes for the temperatures to stabilize. For multiple-frequency operations, the best solution is to choose one frequency then scan-convert all other frequencies to the chosen operational frequency. A low-cost solution is to select a single frequency that favors the most critical images.

3.3.2 Liquid-Crystal Light-Valve Systems

3.3.2.1 Nematic Liquid-Crystal Light-Valve Systems

Optically Addressed Liquid-Crystal Light-Valve System. Hughes Aircraft Company, Industrial Product Division, markets an optically addressed LC light-valve system. The light-valve (figure 13) is a sandwiched assembly of cadmium sulfide (CdS) photosensitive material, nematic LC material, mirrors, and electrode plates. The image is written on a low-intensity monochrome CRT that is optically coupled to the CdS photoconductive material through a fiber optics plate. Illuminated areas of the CRT reduce the photoconductive material's resistance, which alters the applied electric field to the LC material changing the LC molecule's orientation. The net result is light polarization changes that a polarizing filter (called analyzer) detects. Using high-intensity lamps, this technology produces bright high-resolution images. The chief disadvantage is that the CdS photoconductive material response time is typically 70 milliseconds, which smears moving images. Additionally, images displayed for more than 10 to 15 minutes become semipermanent (latent image artifact). Hughes recommends writing the entire display area momentarily in a fully saturated white color when changing images. By not doing so, portions of the old image remain until it is erased by the new image, a process that can take several minutes.

Hughes is developing on a new video-rate light-valve using hydrogenated amorphous silicon photoconductor material to replace the CdS photoconductor material [27]. A full-color prototype demonstrated a clear video image this past year, without smear. Hughes engineers are working to improve the manufacturing yields and to optimize the design for luminance, response, and resolution performance. They are planning production for the latter part of 1992.

Matrixed Addressed Liquid-Crystal Light-Valve System

A. Liquid-Crystal Projector — Light-valve projectors with AMLCD wafers (commonly referred to as LC projectors) as the modulator may become the leading HDTV light-valve system because of the reported activity and investment. Using AMLCD technology in light-valve projection systems takes advantage of the investment activities

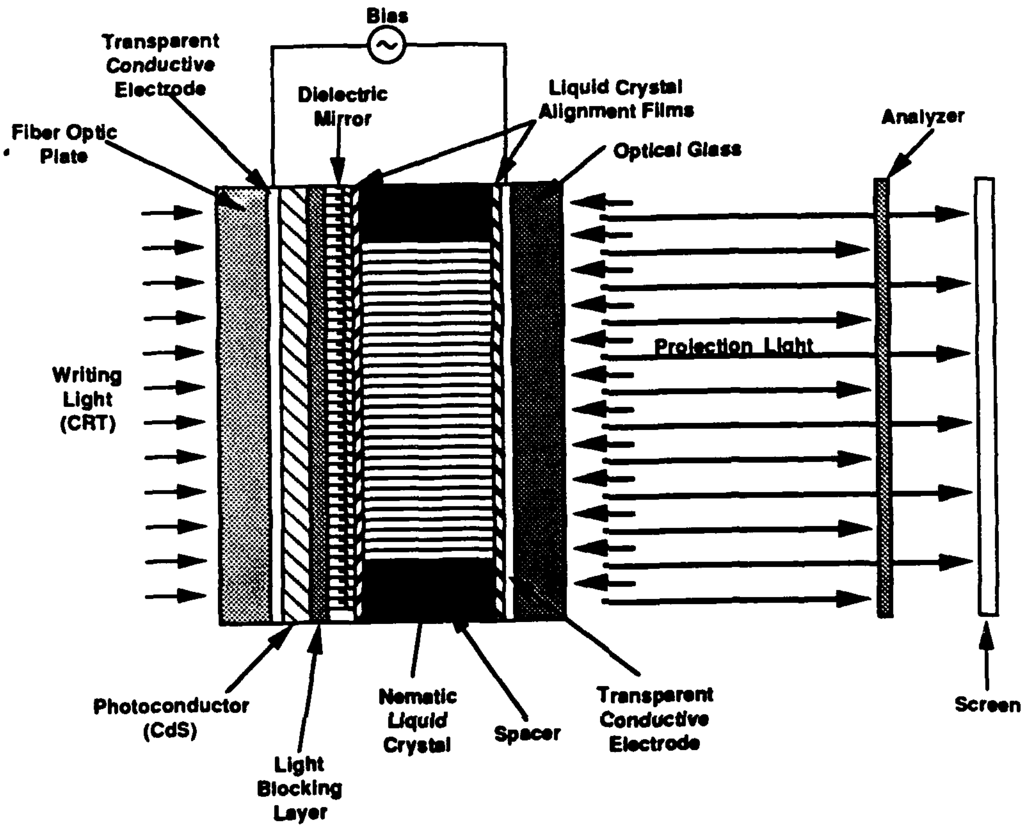

Figure 13. Hughes Liquid-Crystal Light-Valve System

without being impacted by the low manufacturing yields, because small wafer sizes are used. The key challenges are heat dissipation, high brightness, and obtaining the required pixel densities without increasing the wafer size.

In the last two years, Sharp, Sanyo, NEC, Matsushita, Philips, and Seiko-Epson [28-34] have presented their prototype designs. The product development strategy is clearly stated: the LC projectors will first replace CRT projector systems for lower resolution video images, then for high-resolution images. Today, only dim and low-resolution LC projectors are available. For example, portable AMLCD projectors available from Sanyo and Sharp produce 80 to 100 lumens from a single 150-watt metal halide lamp. The resolution is 220 by 300 pixels with plans for 480 by 640 and 480 by 720 pixels. These systems are also being designed into cabinets with high gain screens [35]. By increasing the LC wafer sizes from 3 inches to 5.5 inches, Sanyo (figure 14) and Sharp have obtained resolution exceeding one-million pixels. Sanyo's new 1.5-million-pixel projector is reported to output 180 lumens from a 250-watt lamp and costs $71,000 [36]. Before LC projectors are widely used in the home, developers must also design an inexpensive bright light source that lasts more than 2000 hours, is easy to replace, and will not overheat the LC wafer.

Brighter images require higher intensity light sources, but heat dissipation is already a critical problem. Researchers are developing ways to improve the efficient use of the available light by converting, with little loss, the unpolarized, high-intensity light source into linearly polarized light. As an example of the current low efficiencies, existing LC systems typically experience 60-percent transmissivity loss through the input polarizing stage. NEC has developed a polarization convertor [37] that converts the light source into two orthogonal linearly polarized light components. A polarization rotator then shifts one component 90 degrees and adds it to the second component. NEC reported their convertor to be 95 percent efficient and has proven its performance in an AMLCD projector similar in design to figure 14. They measured over 500 lumens using a 300-watt Xenon lamp and a 4.3-inch amorphous silicon TFT-addressed LC wafer. F. Hoffman-LaRoche Researchers reported [38] a different convertor design that develops three circular polarized beams that can be directed separately to the RGB LC wafers, or the three components can be converted to a single linearly polarized light.

B. LCD Overhead Projection Panels — LCD overhead projection panels have become popular briefing aides by using standard overhead projectors as the light source and standard desk-top computers to store the limited resolution images (up to 640 by 480 pixels). Because LCD technology imposes severe light transmission loss, the output brightness level is low; therefore, most systems require dim rooms for acceptable presentation. Also, the response is slow. However, a large market potential exists, and advanced systems include remote control devices, built-in memory, and floppy disk media to store presentation images without requiring a computer.

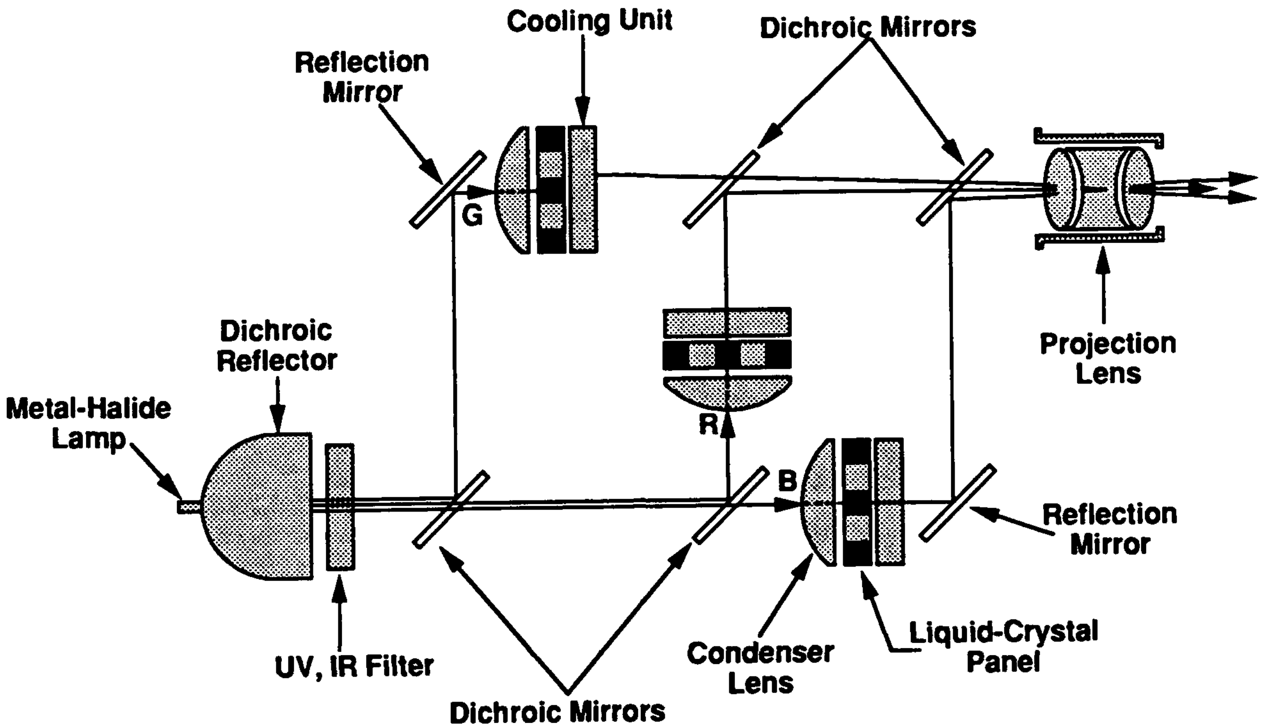

Figure 14. Sanyo Liquid-Crystal Projector

Two full-color designs exist. One design uses LCD panels with each display pixel formed by three subpixels of RGB colored filters. This design produces saturated colors, but because the manufacturing yields are low, the panels are expensive and small.

The second design uses three transparent chip-on-glass, AMLCD panels to subtract the primary colors from the white light source. This design produces nonsaturated colors and suffers light loss in all three panels. Yet, in spite of these drawbacks, this technology is easy to manufacture and is cost effective. Current panels cost about $2000.

Electron-Beam Addressed LC Light-Valve Systems. Tektronix Inc. has reported an electron-beam addressed light-valve design [39,40] (figure 15) that integrates an LC wafer into a unique CRT assembly with two guns: a write gun and an erase gun. The write gun distributes a charge on a mesh layer near the nematic LC surface to switch that location to a transmissive state. The erase gun removes the accumulated charges each frame cycle to prevent the ion buildup in the LC material, which can cancel the applied field. The high-intensity light beam projects through the CRT assembly and then passes through an analyzer to extract the polarized image. Tektronix's goals are to produce bright, 1200- to 1500-line images at high refresh rates.

3.3.2.2 Smectic LC Light-Valve Systems

Greyhawk Inc. produces a thermally addressed light-valve system (figure 16) that uses a laser beam to heat smectic LC material into the fluid state and then applies an electrical field to change the molecular orientation [41]. The image becomes fixed when the material cools and requires reheating to change. The Greyhawk system produces exceedingly high-resolution (3400 by 2200 pixels) and brightness (500 lumens) full-color images but has relatively long image update times—typically 5 microseconds per pixel or 3 minutes per image. Greyhawk also uses multiple projectors to output approximately 700 lumen images on a 6.5- by 10-foot screen with a reported 5000 by 7700 pixel resolution. This system is now displaying map data for the Paris Police.

3.3.2.3 Surface-Stabilized Ferroelectric LC Light-Valve Systems

Greyhawk Inc. engineers have reported a video rate prototype system [42]. This system is optically addressed like the Hughes system, using either a laser beam or monochrome CRTs to address the photoconductor material. The LC layer is surface-stabilized ferroelectric LC (SSFLC) material is smectic LC molecules confined by micron-spaced plates to ensure bistate switching. Because the SSFLC spacing is less than nematic spacings, thinner photoconductor material is used to significantly improve the on/off switching ratios. SSFLC technology has sharp switching characteristics, but lacks inherent gray scale capabilities, and its fast response time depends on achieving favorable viscosity and spontaneous polarization performance [43]. Successful commercialization may

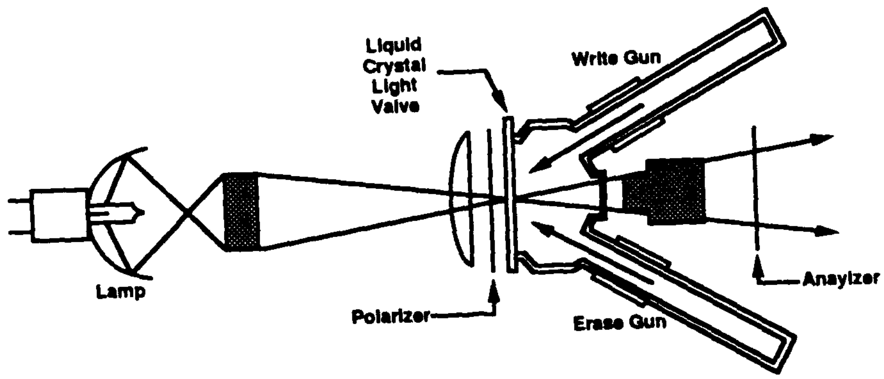

Figure 15. Tektronix Electron-Beam Addressed System

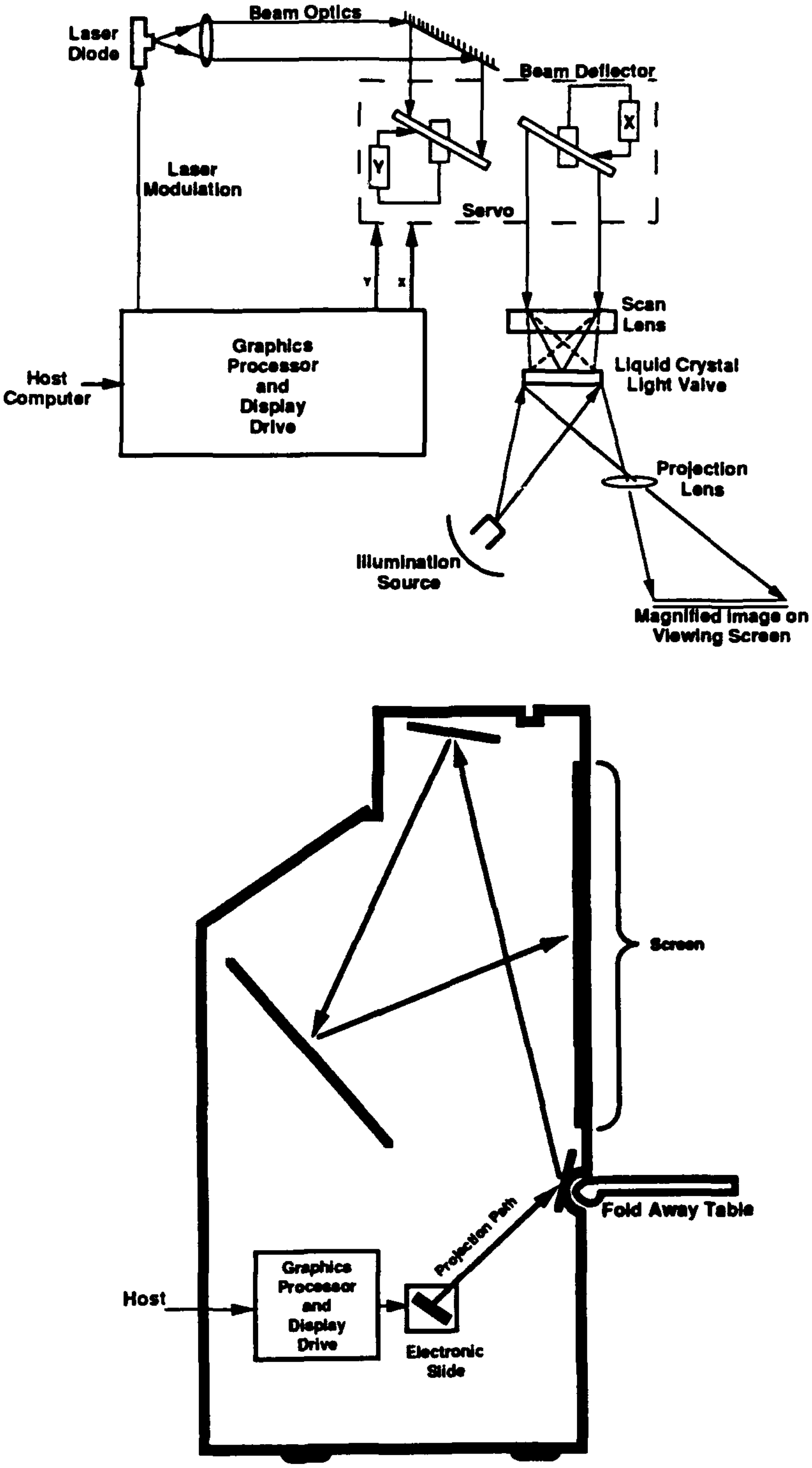

Figure 16. Greyhawk Light-Valve System

eventually depend on achieving mechanical stability, resolving the gray scale and temperature sensitivity problems. Matsushita [44,45] and Keiko University [46] are also developing SSFLC light-valve systems. Matsushita recently reported a 1280 by 1280 pixel SSFLC display.

3.3.2.4 Polymer Dispersed Light-Valve Systems

A promising large-screen LC display technology uses Polymer Dispersed LC material, which consists of small nematic droplets (2 to 3 microns) dispersed in polymer films. Common names for this technology include: Nematic Curvilinear Aligned Phase (NCAP), Polymer Dispersed Liquid-Crystal (PDLC), Liquid-Crystal Polymer Composite (LCPC), and Encapsulated LC material. With no voltage applied, the randomly aligned nematic droplets scatter the high-intensity light beam. With voltage applied, the droplets align themselves with the electric field, making the panel transparent. Because this technology scatters light instead of absorbing light and requires no polarizers, the system provides brighter images than twisted nematic display systems. Large area polymer sheets (1 by 3 meters) are available, and these polymer sheets can be flexible and custom cut to any shape. The near-term applications are low-resolution large area signs, window applications and because of cost, automotive applications. The potential also exists for high-resolution, large-screen display systems because of the low transmissive light losses.

The key players in this technology are Asahi Glass, Japan Broadcasting Company (NHK), and OIS/Kent State. Taliq Corporation, a subsidiary of Raychem, recently closed its NCAP operation. Asahi Glass plans to market a 65 to 100 lumen, 1000-line full-color system for $2000 based on the concept shown in figure 17. Their prototype model now provides 240 by 360 pixels [47]. Japan Broadcasting Company (NHK) is developing a PDLC light-valve design (figure 18) similar to the optically addressed Hughes light-valve design [48]. Their first model outputs 320 by 320 pixels with a claimed 800-lumen peak brightness.

3.3.3 Deformable Viscoelastic Light-Valve Systems

Several universities and manufacturers (New York Institute of Technology [49], HHI Berlin [50], Xerox, ETH Zurich, and Weizmann Institute) have experimented with thin metallized deformable viscoelastic light-valve systems. They predict these systems can produce bright (over 5000 lumens) HDTV quality images when driven by active-matrix addressing circuitry. The system design (shown in figure 19) is similar to the oil-film light-valve discussed earlier. Instead of using oil films, these systems use a thin metallized coating bonded by evaporation on elastomer material. Electrostatic forces deform the reflective coating when excited, and a Schlieren optics system detects the resulting diffraction patterns. The system's success depends on developing stable materials and an efficient manufacturing process.

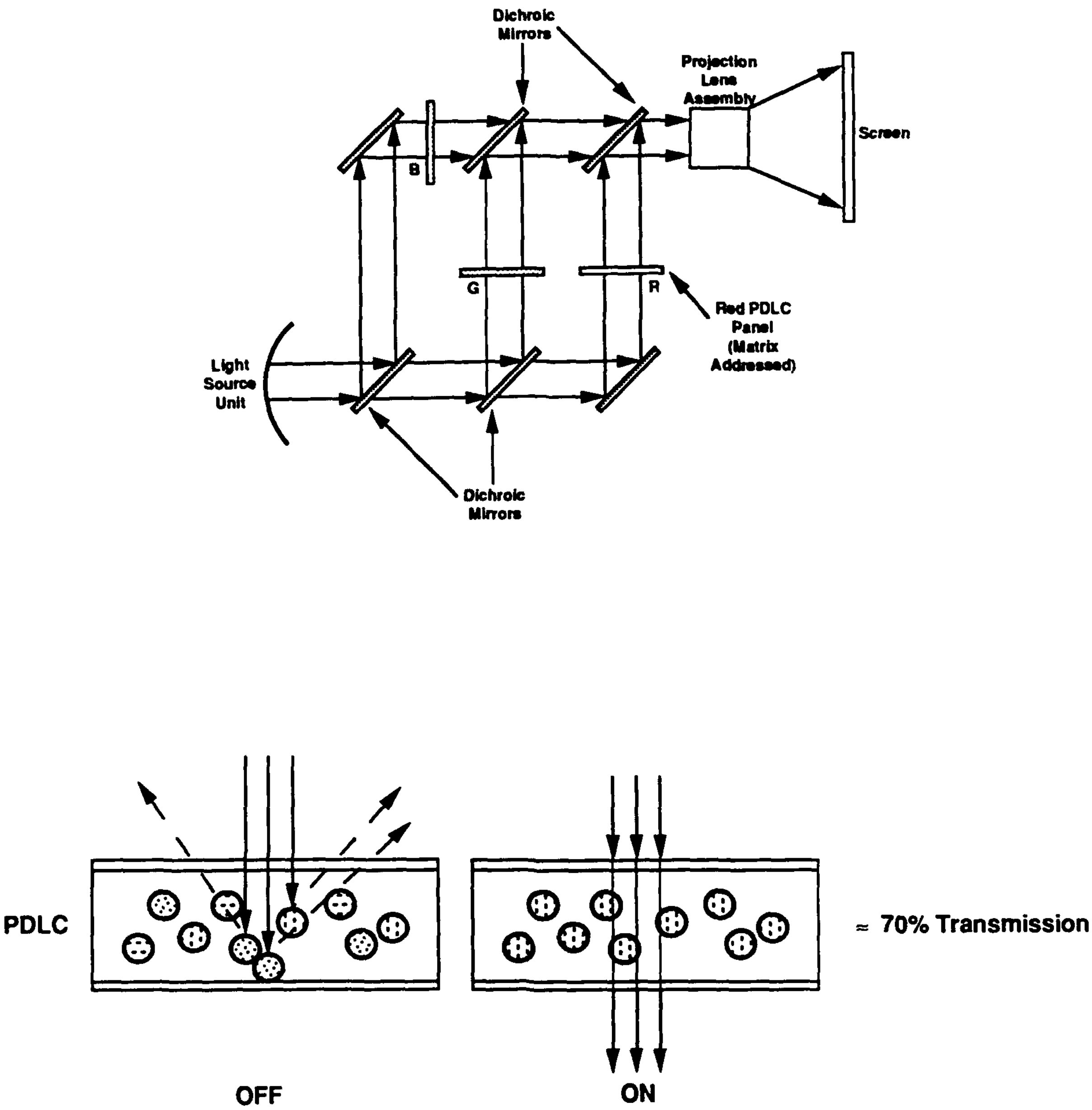

Figure 17. Asahi Glass Polymer Dispersed Liquid-Crystal Display (Matrixed Addressed)

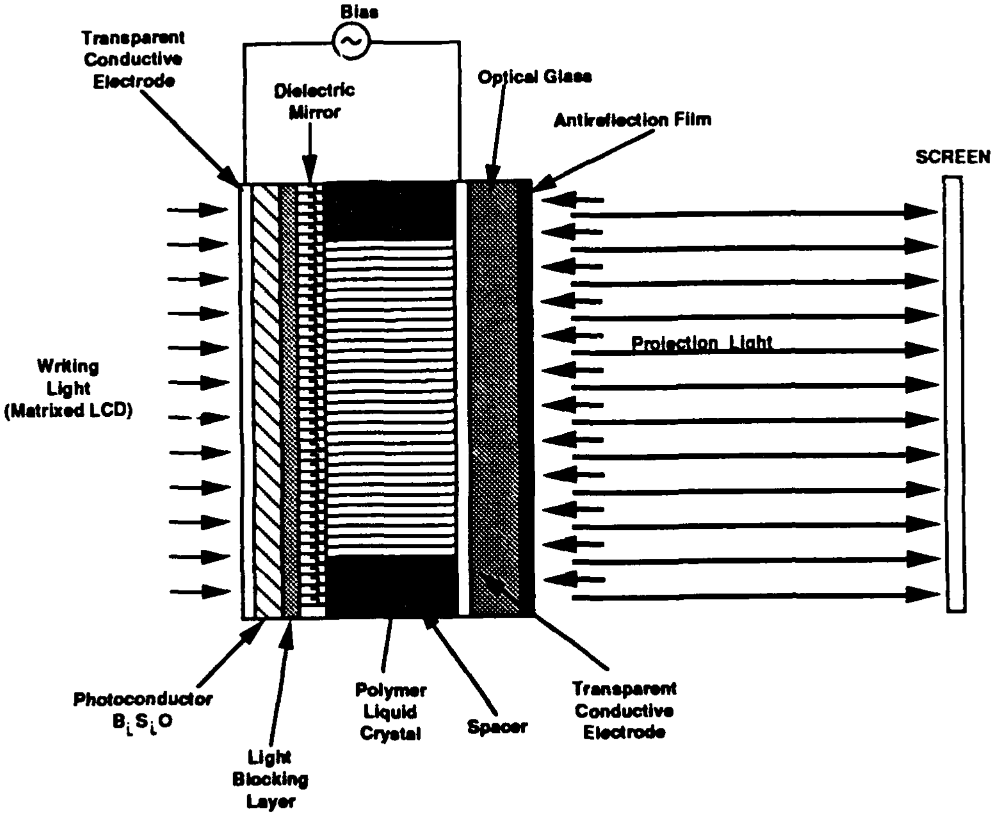

Figure 18. Japan Broadcasting Company Polymer Dispersed Light-Valve System (Optically Addressed)

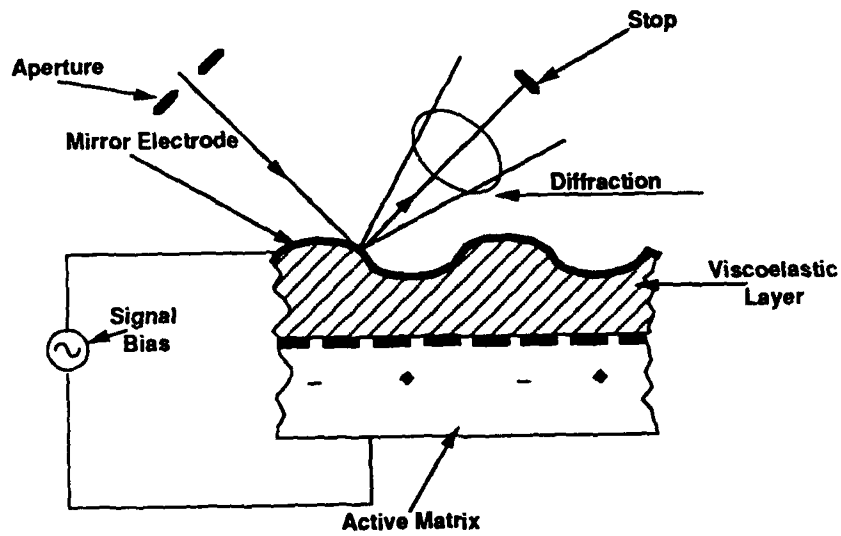

Figure 19. Deformable Viscoelastic Light-Valve System

3.3.4 Deformable Mirror Light-Valve Systems

Texas Instruments/David Sarnoff Research Center is using micromotor technology to develop a deformable mirror devices (DMDs) display of 2 million, 20 micron, square silicon mirrors (figure 20) to direct light transmission at the pixel level. The manufacturing challenge is great because of the small dimensions and the demands on new materials and processes. With DARPA support, Texas Instruments is planning commercialization by 1993.

3.3.5 Fiber Optics Large-Area Screens

Several companies (TRU-LYTE, Toray, ADTI, and Mitsubishi) use fiber-optic cables to physically expand a small illuminated area to a large area. For example, one system expands a fiber optics bundle from a 1- by 1-inch area to 6- by 6-inch screen modules (figure 21). The fiber optics bundle is compressed at one end and illuminated by a high-intensity light-valve system. At the screen surface, the bundle is expanded so each displayed pixel corresponds to a single fiber with a micro-lens to disperse the light. Reports indicate that [51] television-quality images can be presented on these display screens with plans to produce HDTV images. High manufacturing cost, brightness tradeoffs with the viewing angle, and high maintenance associated with the expensive high-intensity projection system may limit the widespread use of these systems.

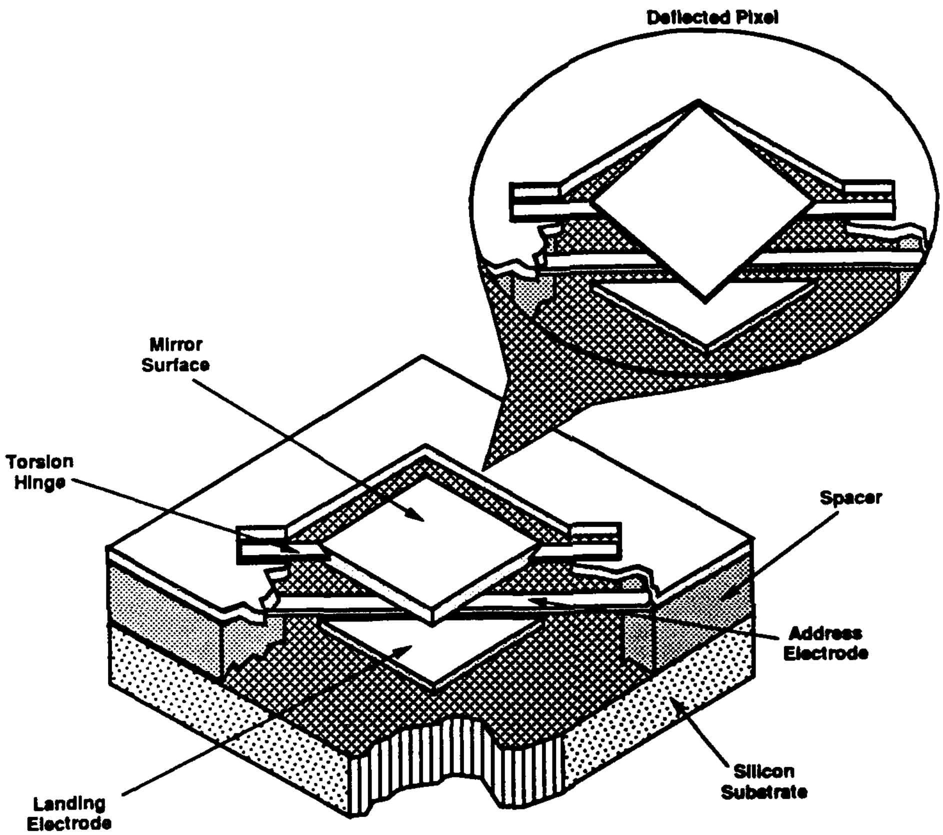

Figure 20. Texas Instruments/David Sarnoff Research Center
Deformable Mirror Display System

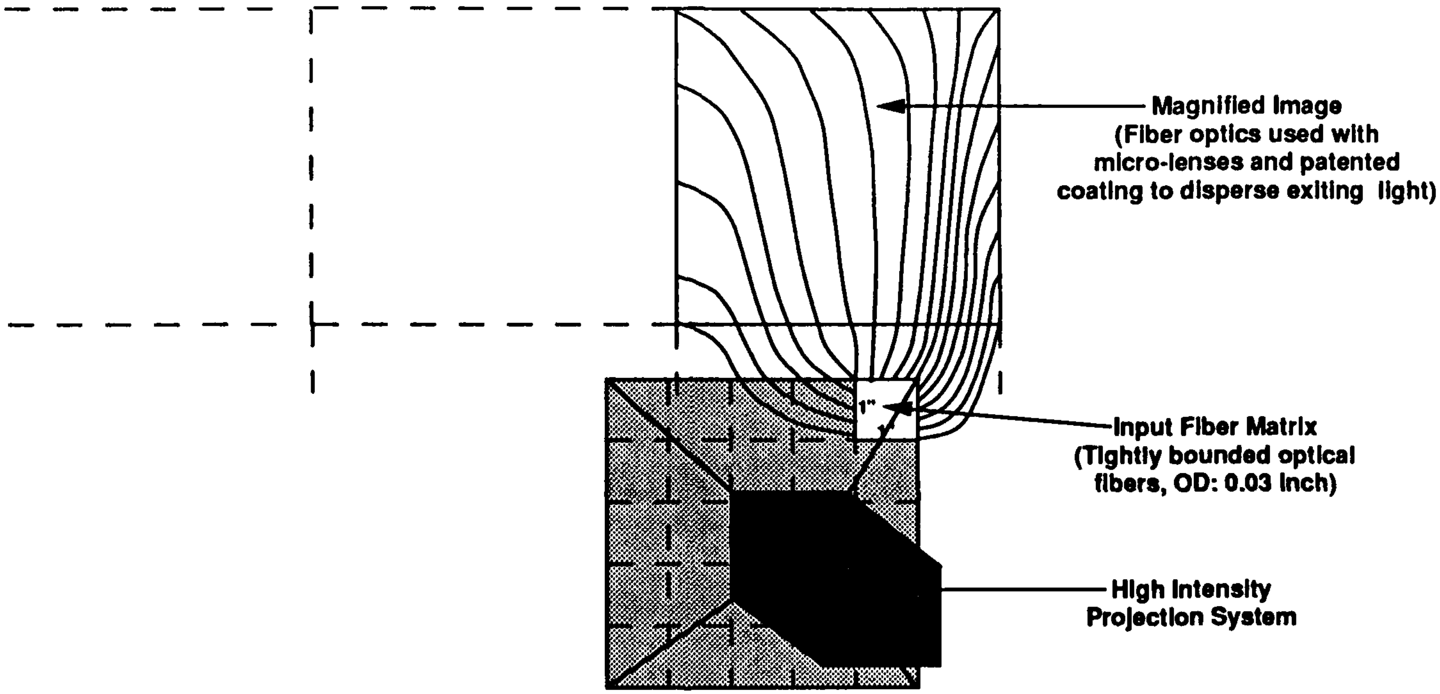

Figure 21. Fiber Screen

SECTION 4

DARPA AND MCC INITIATIVES

DARPA HDTV initiatives are assisting large-screen display technology development, but industry experts feel the commitment is small compared to Japanese initiatives. In 1989, DARPA awarded $30 million seed money over a three-year period to several companies to develop high-definition display technologies.

Three proposals use light-valve technology. Raychem/Xerox is using PDLC technology. Texas Instruments/ David Sarnoff Research Center is developing the micromotor technology. Projectavision Inc. is researching a proprietary light-valve using AMLCD technology. With $1 million funding, they developed a 5-inch diagonal display and plan to introduce a 15-pound projector for $1500.

Magnascreen Corporation is developing a large-area flat panel display constructed from seamless tiled LC modules, and Zenith is researching an HDTV display based on their flat tension mask (FTM) CRT design. Nitcor, a company formed from the old Visulux Corporation, is using laser technology in a video rate projection system, and Photonics is developing full-color plasma technology. MCC and Coloray are developing FED devices.

While these results are still developing, DARPA recently solicited new proposals in seven high-definition research areas: displays, manufacturing equipment, display enabling technologies (material and manufacturing processes), processors, storage devices, imagers, and signal distribution. DARPA is now emphasizing manufacturing and materials instead of display technology because they want to acquire flat-panel manufacturing expertise. Of the 365 proposals received in March 1991, DARPA asked 105 companies to submit detailed proposals for the second round of evaluations in May 1991. Additional funding was provided to support this second round of developments.

In June 1991, MCC formed a new American Display Consortium (ADC) to increase the competitiveness of the U. S. display industry by linking the research activities of individual companies. So far, nine companies have joined the ADC: Cherry Display, Electro-Plasma, Magnascreen, OIS Optical Imaging Display, Photonics, Planar, Plasmaco, Standish Industries, and Tektronix. This consortium is still in the start-up phase with the initial goals to expand its membership and conduct research related to the design, test, and production of flat-panel displays.

SECTION 5

PERFORMANCE DATA

Table 1 provides a summary of nominal performance for the display systems discussed in this paper. The system performance data was obtained either from the manufacturer's specifications or from their short-term design goals, or have been verified in our laboratory. The luminous efficiency data in lumens per watt includes the total system — display and driving electronics. Blanks indicate that the data was not available.

The display size for direct view systems is based on reported research or on actual production sizes. Since the display size of projection systems is adjustable and can be increased without limit, we have listed the maximum size corresponding to 8 footlamberts average luminance. Eight footlamberts is the MIL-STD-1472C preferred requirement for group viewing of optical projection systems, which for most viewing environments helps insure the image is not washed out by the room ambient light. Even with this requirement met, the light-ambient levels must be carefully controlled to ensure the displayed contrast ratio is acceptable. The status column provides comments on technology limitations and production status.

Included in table 1 are the design goals for HDTV [52], command and control [1,2], and the electronic cinema (small and large theater) [3]. By comparing the requirements to the performance data, one can see that few display technologies now meet all requirements. This deficiency should change in the next two to five years, considering the research and development activity in progress. Nearly half of the technologies in table 1 are developmental technologies, which indicates the interest in the industrial community to provide suitable large-area display products.

Table 1. Full-Color Display Technologies

Technology	Output (lumens)	Resolvable Resolution (color)	Size (ft^2)	Eff. (lm/watt)	Full-Color Status (areas of technology improvement)
Direct View					
CRT	60	1100	4.5	0.2	Mature technology (low cost/large size/high resolution)
Flat CRT	40 fL[1]	110 x 26	0.004	----	Developmental (manufacturing process)
FED	100 fL	80	0.08	3 (est)	Developmental (manufacturing process)
AMLCD	50	1152 x 900	0.64	0.3	Maturing (mfg. yields, size)
Mosaic LCD	50	Low	>30	0.2	Mature (resolution, heat dissipation)
Cathode Luminescence	>1000	Low	>50	0.3	Mature (resolution)
LED	>1000	Low	>20	0.5	Limited color products (blue LED)
Plasma	70	800 x 500	3.7	0.15 - 0.5	Initial product offering (blue phosphor, mfg. costs, size)
TFEL	1	320 x 240	0.12	0.1	Developmental (blue phosphor, mfg. costs, size)
Projection					
CRT	30 - 200	500 - 900	25	0.5	Mature (brightness, resolution)
Self-Contained CRT	100 - 300	500 - 900	38	0.5	Mature (brightness, resolution)
Laser	500	500	60	0.03	Developmental (operating cost, reliability)
3-D Laser	10 fL	500	7	----	Developmental (resolution, operating cost)
Oil film Light Valve	250-5000	400 - 1000	600	0.2 - 2	Mature product (resolution, flexibility, maintenance)
Optical Addr. LCLV	500-2500	800 - 1300	300	0.5	Mature product (reduce smear)
LC Projector	*80-180*	750	20	0.5	Initial product offering (mfg. yields, resolution, light output)
LCD Overhead Panel	80	640 x 480	10	0.1	Mature product (brightness, resolution)
Electron Beam Addr. LCLV	400	640 x 480	50	1	Developmental
Smetic LCLV	500-1500	2000 - 5000	5.2, 65	0.3	Mature product (update time)
Ferroelectric LCLV	100	2000	4.8	0.6	Developmental (gray scale, power, temperature sensitivity)
Polymer Dispersed LCLV	860	320 x 320	110	----	Developmental
Viscoelectric Light Valve	5000 (est)	1000	600	----	Developmental
Deformable Mirrors	----	----	----	----	Developmental (manufacturing process)
Fiber Screen	----	500	60	----	Limited product offering (cost, maintenance)
Requirements					
HDTV	>200[2]	>1000 lines	>5	>0.3	
Command/Control	500-1000	>1000 lines	>50	>0.5	
Small Cinema	2000	>1500 lines	200	>1	
Large Cinema	10000	>1500 lines	500	>1	

1. Footlamberts (fL), a measure of luminance, is related to the luminous flux (lumens) by the display area (ft^2); fL = lumens/ft^2.

2. 200 lumens is acceptable for a 5 ft^2 display area provided the contrast ratio is 50:1 with 0.9 fL reflected ambient illumination from the display's front surface. Most large-screen display systems require more than 200 lumens to meet the HDTV 50:1 contrast ratio requirement.

SECTION 6

CONCLUSION

Large-screen display technology is rapidly changing. Similar to the 1960s space race when man landed on the moon and spawned many new ideas and technologies, HDTV, with its alluring large potential market, is driving nations and companies to commit large amounts of research and engineering investments. The fallout from this technology innovation will be significant improvements in manufacturing, materials, and visual image quality.

In this report, we presented the large-screen display developments known to us. Based on this assessment, the AMLCD light-valve system promises to improve and will replace CRT projection systems for low brightness (less than 200 lumens) applications. For the high brightness applications, oil-film and LC light-valve systems will continue to provide bright, high-visual resolution images.

There are many flat large-area display technology candidates, but no clear winner for the 40-inch television that can hang on the wall. Customers will only pay a small premium over existing systems for HDTV quality, which some experts feel should be $2000 to $3000 maximum. Only improved manufacturing yield will reduce the product costs to these levels. For this reason, future assessments must look at manufacturing and material process innovations instead of display quality achievements.

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GLOSSARY

ADC	American Display Consortium
AMLCD	active-matrix liquid-crystal display
AO	acoustic-optical
CdS	cadmium sulfide
CRT	cathode-ray-tube
DARPA	Defense Advanced Research Projects Agency
DMD	deformable mirror devices
FED	field-emission display
FTM	flat tension mask
HDTV	high-definition television
KIT	Kanazawa Institute of Technology
LC	liquid-crystal
LED	light emitting diodes
MCC	Microelectronics and Computer Technology Corporation
MIM	metal insulator-metal
MITI	Ministry of International Trade and Industry
PDLC	polymer dispersed liquid-crystal
RGB	red-green-blue
SID	Society for Information Display
SSFLC	surface-stabilized ferroelectric liquid-crystal
TFEL	thin-film electroluminescent
TFT	thin-film transistor
VFD	vacuum fluorescence display
VGA	video graphics array